Phytoplankton community structure and distribution in the nearshore zone of Lake Ontario

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Keywords: phytoplankton, nearshore, Lake Ontario, environmental stability, community structure

Abstract

Spatial and temporal distributions of phytoplankton were studied during 1979 in the nearshore zone of Lake Ontario. Genera such as *Dinobryon, Oscillatoria*, and *Gymnodinium* tended to be found at discrete depths whereas other genera such as *Cryptomonas* and *Rhodomonas* tended to be more uniformly distributed throughout the water column. The discrete depth distribution of some of these genera compared with the weak thermal stabilization of the area suggests depth selection and habitat preference within the algal community.

Physical processes probably played a major role in regulating the timing and duration of vertical diatom pulses, and resuspension from the sediment played a major role as to the timing of the autumn growth. Vertical mixing in the nearshore zone was sufficient for some diatom genera such as *Tabellaria* to maintain populations throughout the summer. These mixing processes, however, affect the stability of community structures and associations that develop within the water column. The role of physical processes and their potential effects on algal production in the Great Lakes is discussed.

Introduction

The major problems encountered when studying the phytoplankton of the Great Lakes are associated with the size of the lakes and the complexity of physical processes associated with large lakes. Munawar & Munawar (1975) stressed the importance of phytoplankton flagellates and nannoplankton in the Great Lakes, but little is known about the ecological requirements of these species and the factors that regulate their abundance and distribution. It is apparent that the phytoplankton of the Great Lakes are capable of a large amount of nutrient recycling (Stadlemann & Fraser, 1974), and Harris & Lott (1973) illustrated the sensitivity of these populations to changes in the light regime. Very little is known, however, of the vertical structure of phytoplankton populations particularly as related to the physical processes which determine the thermal stabilization of the water column.

Phytoplankton species composition in the northwest nearshore zone of Lake Ontario has been studied by Nalewajko (1967) and Michalski (1969). Long term trend information on composition has been reported by Schenk & Thompson (1965) although the units they used to describe algal crops (areal standards unit) do not permit an estimate of plankton abundance. Reported inshore algal volumes of the area are in the range of $0.2\text{–}2.3 \times 10^6$ μm^3.ml (Munawar *et al*, 1974), while chlorophyll concentrations ranged from 1.9 μg.l to 8 μg.l.

There have been only a few productivity studies in this region of Lake Ontario, and measured rates of primary productivity are low compared with

Hydrobiologia 114, 51–66 (1984).
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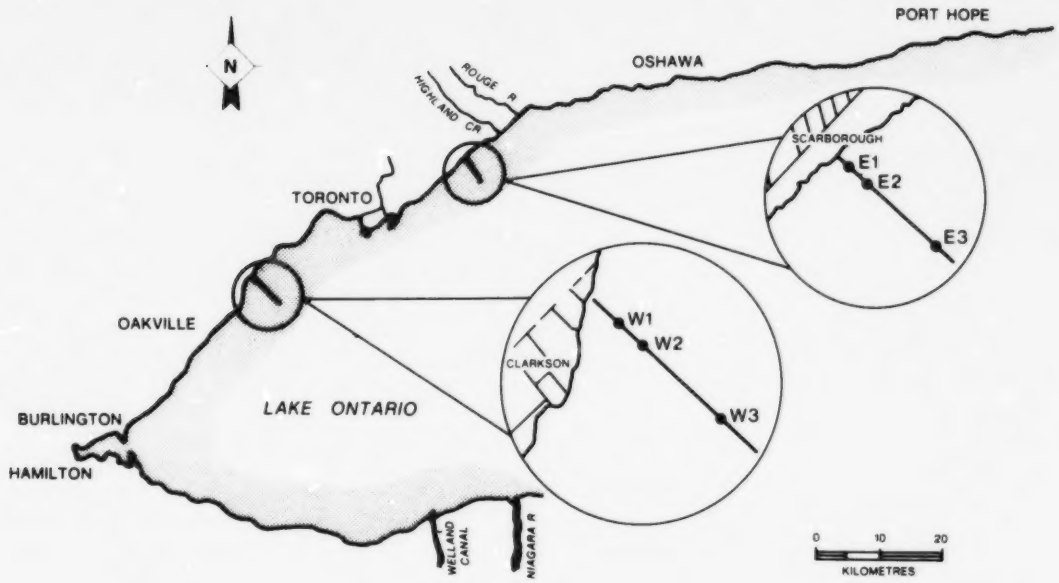

Fig. 1. Sampling transects and sampling stations in the Toronto area of Lake Ontario.

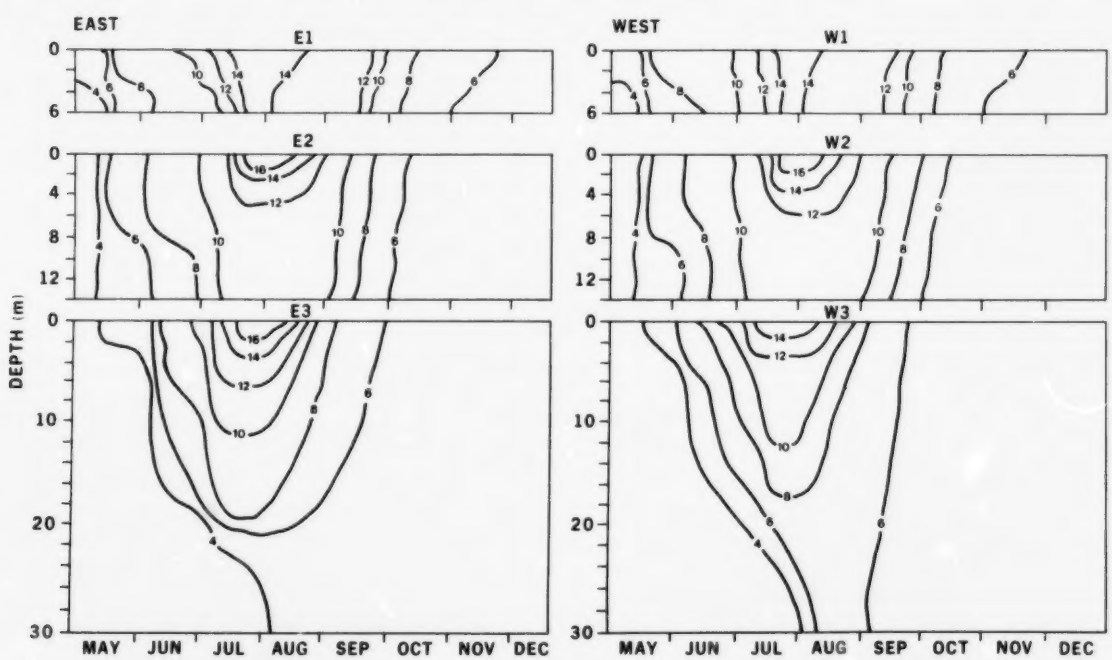

Fig. 2. Thermal profiles (° C) for two transects in the Toronto area of Lake Ontario, 1979.

other lakes of similar nutrient levels. Glooschenko *et al* (1974) measured inshore productivity in Lake Ontario to be between 120 and 1080 mg C.m $^{-2}$.d, whereas Stadlemann *et al* (1974) measured inshore productivity between 119 mg C.m $^{-2}$.d to 2103 mg C.m $^{-2}$.d. Stadlemann & Moore (1974) noted that up to 50% of the daily production occurred between 1000 and 1400 h, although Harris *et al* (1980) found that changes in the ratio of the euphotic depth: mixing depth (Zeu:Zm) could alter productivity substantially. Therefore productivity in nearshore waters is not only a function of nutrient availability (Schelske, 1979) but is also related to physical factors such as retention times, internal wave motions and seiche effects which influence water column stability (see Haffner *et al*, 1982).

Michalski (1969) noted a lack of community and population structure in the nearshore zone of Lake Ontario, and the work of Haffner *et al* (1980, 1982) and Ignatiades (1979) suggest that physical processes could affect phytoplankton community structure and primary production in nearshore zones. An investigation of the temporal and spatial structures of nearshore phytoplankton communities was initiated in 1979. The object of the study was to determine the composition, abundance and vertical distribution of nearshore algal communities and determine the factors which regulate community structures in these areas.

Methods

Study design

The study of phytoplankton populations from the Toronto area of Lake Ontario complimented ongoing work of the Water Resources Branch of the Ontario Ministry of the Environment (MOE). Two transects were chosen for the study. Each transect consisted of three stations, situated at the 8 m, 17 m, and 32 m depth contours. One transect (E) was located 5 km east of Toronto Harbour, and the other (W) was 6 km west of the harbour (Fig. 1). Inshore stations (E1, W1) were sampled at 0.5, 3 and 6 m depth, midshore stations (E2, W2) were sampled at 0.5, 3.0 and 6.0, and 12 m depth, and offshore stations (E3, W3) were sampled at 0.5, 3.0, 6.0, 15, 20, 25, and 30 m depth.

Stations were sampled weekly from May to November, 1979, except on occasions where logistic problems or unfavourable weather conditions were encountered. Algal samples (fixed with Lugol's Iodine) were analyzed at the University of Windsor, while chemical samples were analyzed by the MOE laboratory. While collecting the algal and chemical samples, temperature profiles were determined using a thermistor and light penetration was measured. Light penetration was determined using a Kahlsico photometer with clear, blue and green filters (420–670 nm; 420–480 nm; 490–570 nm).

Samples for chemical analyses were filtered immediately (where required) on board ship, and stored in an ice chest until delivered to the laboratory. Phosphorus (total and filtered reactive), silica (silicia acid and silicate), and nitrogen (NO_2+NO_2, NH_3) were determined using the procedures outlined in Standards Methods (APHA, 1976). Chlorophyll *a* was determined spectrophotometrically, and values were corrected for phaeopigments.

Phytoplankton enumeration was performed using the Utermohl technique and the counting procedure described by Lund *et al* (1958). A modified sedimentation tube (Evans, 1972) was used to prepare the phytoplankton for identification and enumeration. The entire chamber was surveyed for larger forms (i.e. those species with cell volumes greater than 600 μm^3) at 300 × magnification. This method avoids any bias in the biomass estimates resulting from clumping or non-random distribution of organisms on the slide. Small species were enumerated by counting 10 fields at 600 × magnification. Cell sizes were determined using a graticule and cell volumes were estimated from these measurements. Cell volumes were calculated on a monthly basis for the common algal species.

Phytoplankton were identified using Huber-Pestalozzi (1941–1968), although other references were consulted (Prescott, 1962; Fritsch, 1945).

Results

Temperature

Figure 2 illustrates the temperature profiles observed along the East and West Transects during 1979. Temperature increased from 4 °C in late April to 16 °C in the surface waters by late July. Except during the latter period there was little evidence of strong thermal stabilization in the water

Table 1. Light penetration expressed in terms of vertical attenuation at sampling sites in Lake Ontario.

E ± 1S.D.						
Green	0.45 ± 0.08	0.32 ± 0.09	0.32 ± 0.09	0.45 ± 0.09	0.47 ± 0.08	0.41 ± 0.11
Blue	0.53 ± 0.10	0.45 ± 0.17	0.46 ± 0.08	0.64 ± 0.11	0.62 ± 0.17	0.51 ± 0.20
Clear	0.40 ± 0.14	0.35 ± 0.11	0.34 ± 0.13	0.49 ± 0.09	0.48 ± 0.12	0.43 ± 0.13

column. Temperatures changed very gradually with depth without the formation of distinct density layers.

When interpreting the information provided in Fig. 2 it is essential to be aware of the dynamics of the physical stresses that are imposed on a nearshore environment. The thermal structure is continually modified by physical processes such as thermal bar formations, internal waves and upwellings so that data collected at periodic intervals do not reveal the spatial and temporal variability inherent to nearshore zones. Problems of interpreting thermal structure in this area of Lake Ontario were previously encountered by Stadlemann *et al* (1974) who reviewed the complexity of relating biological and chemical events to the thermal characteristics of nearshore zones. However in Fig. 2, because of the weak thermal gradients it can be assumed that a fair amount of vertical mixing occurs within a nearshore water column. It would then follow that one would not expect little vertical structure would be found in the phytoplankton communities of these water columns.

Light attenuation

Table 1 summarizes the vertical attenuation (ϵ) of solar radiation in the northwest section of Lake Ontario during 1979. As indicated in Table 1, there were strong spectral differences in the penetration of light. Blue light was more rapidly absorbed than green, suggesting that small particles played a major role in attenuation of radiant energy in the waters of the northwest nearshore zone of Lake Ontario. Comparison of light attenuation between the two transects using T-test indicated that the vertical light attenuation coefficient was higher ($P < 0.05$) along the western transect. The euphotic zone was estimated to be above 10 metres along the eastern transect, and above 8 metres along the western transect.

If the ratio of ϵ_{blue} and ϵ_{green} was used as a measure of the effects of small suspended particulates, it was found that the ratio varied little (1.2–1.4) among the nearshore, midshore and offshore stations. This would indicate that small (possibly nonbiological) particles dominated light attenuation out to the offshore stations E3 and W3. One-way ANOVA indicated that there was no significant nearshore/offshore gradient of light penetration ($F = 3.6$, $P > 0.05$).

Chemistry

During 1979, there were statistically significant $P < 0.05$ (determined by 2-way ANOVA) nearshore-offshore gradients in the top six metres of the water column in total phosphorus along both transects (Table 2). On the eastern transect, total phosphorus in the upper 6 metres of the water column declined from an annual average of 17.2 μgP.l at the inshore station to 14.1 μgP.l at the offshore station. A similar pattern was observed on the western transect where the annual average inshore concentration was 22 μgP.l and the corresponding offshore value was 18.3 μgP.l. Phosphorus concentrations along the western transect averaged 5 μgP.l higher than the eastern transect throughout the year.

Filtered reactive phosphorus exhibited a similar pattern to total phosphorus. Along the eastern transect, the mean annual filtered phosphorus concentration declined from 7.9 μgP.l in the nearshore to 6.7 μgP.l at the offshore station (Table 2). The western transect had higher concentrations and illustrated a more distinct inshore-offshore gradient (11.1 μgP.l to 8.1 μgP.l).

There was no inshore-offshore gradient of silica (Table 2), and concentrations showed little variation throughout the year. This might be a result of the earliest samples being collected in late April near of the peak of the vernal diatom pulse. Measured silica concentrations were low enough to re-

Table 2. Nutrient status of the nearshore waters of the north western section of Lake Ontario. E_1, E_2, E_3 represent the eastern transect (nearshore, midshore and offshore) and W, W, W represents the western transect. Nutrients presented as mean, range, standard deviation and F test of inshore-offshore differences.

Station	Mean concentration	Range	Sd	F* value
E1	17.2	13–23	4.3	3.7**
E2	15.4	11–26	3.5	
E3	14.1	8–23	4.3	
W1	22.1	11–33	6.2	2.8
W2	19.6	8–28	6.3	
W3	18.3	8–25	5.3	
Nearshore filtered phosphorus gradient (μg.l)				
E1	7.9	5.9–13.7	2.0	3.2**
E2	6.9	4.9–16.9	1.2	
E3	6.7	4.3–14.9	2.0	
W1	11.1	7.2–24.0	3.8	7.0**
W2	8.9	6.0–13.8	2.5	
W3	8.1	4.7–18.6	2.0	
Nearshore Si gradient (μg.l)				
E1	125	50–250	96	0.11
E2	140	50–200	150	
E3	138	50–450	116	
W1	121	50–350	81	0.50
W2	106	50–500	68	
W3	100	50–350	71	
$NO_2 + NO_3$ nearshore gradient (μg.l)				
E1	243	190–380	91	0.96
E2	214	90–310	92	
E3	211	120–320	84	
W1	253	100–450	104	1.90
W2	223	110–420	114	
W3	193	10–360	120	
NH_3 nearshore gradient (μg.l)				
E1	27	12–112	28	2.5
E2	18	6–42	18	
E3	14	1–54	18	
W1	32	4–113	29	6.5**
W2	19	2–73	20	
W3	12	6–62	7	

* Variances tested for similarity using Bartlett's χ^2.
** <0.05; $n = 17$.

present a potential silica depleted (or limited) situation as concentrations ranged from 50–500 μg.l. Hughes and Lund (1962) observed that silica levels could be reduced below 25 μg.l by the addition of phosphorus, and asserted that some diatom species were capable of silica incorporation at even lower concentrations (see also Jorgensen, 1957; and Kilham *et al*, 1977).

There was evidence of a weak inshore-offshore gradient in the top 6 metres of the water column in nitrite plus nitrate concentrations (Table 2), but this gradient was not significant at the 5% level. Concentrations (200 μgN.l) were similar on both the eastern and western transects and were sufficiently high to indicate that nitrogen was not a limiting nutrient in 1979.

Ammonia showed a non-significant inshore-offshore gradient along the eastern transect, but a pronounced gradient along the western transect (Table 2). The ammonia gradient was very consistent throughout the year, and similar gradients have been associated with the mixing of inshore and offshore water masses (Palmer, 1972).

There was no statistical difference ($p > 0.1$) in the distribution of nutrients with depth as would be expected with the weak thermal gradients (see Fig. 2) that develop in this area of Lake Ontario (see Haffner *et al*, 1983).

Excluding silica, ranges of concentrations for phosphorus and nitrogen observed along the transects, and through the water columns would suggest that nutrients would not regulate the distribution of the algal community. The role of silica, however, could not be assessed as observations were initiated while the vernal diatom growth was in progress (see discussion).

Phytoplankton

The predominant phytoplankton groups observed along the transects were diatoms, cryptomonads, and green algae. Despite the nutrient-enriched condition of these nearshore waters, blue-green algae were relatively scarce.

Figure 3 summarizes the calculated total algal volume for the year 1979. What was most striking was the consistency of the algal volumes – they frequently exceeded 10^6 μm^3.ml (1 mm^3.l), yet few periods of peak standing crops were observed. The September maximum (6.9×10^6 μm^3.ml at Station

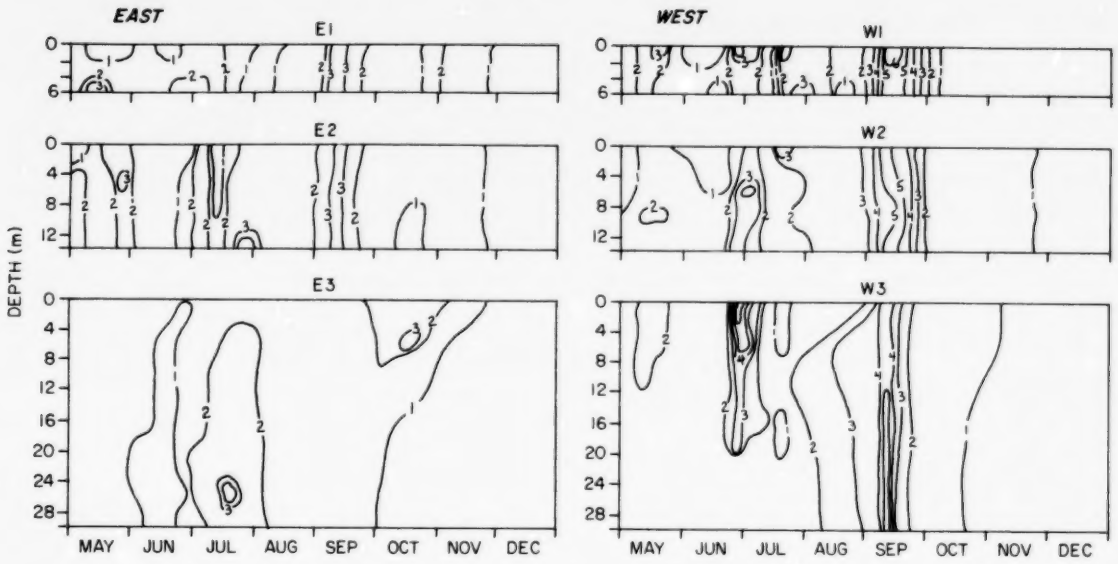

Fig. 3. Algal volumes along two neashore transects in Lake Ontario ($\mu m^3 \times 10^6$/ml).

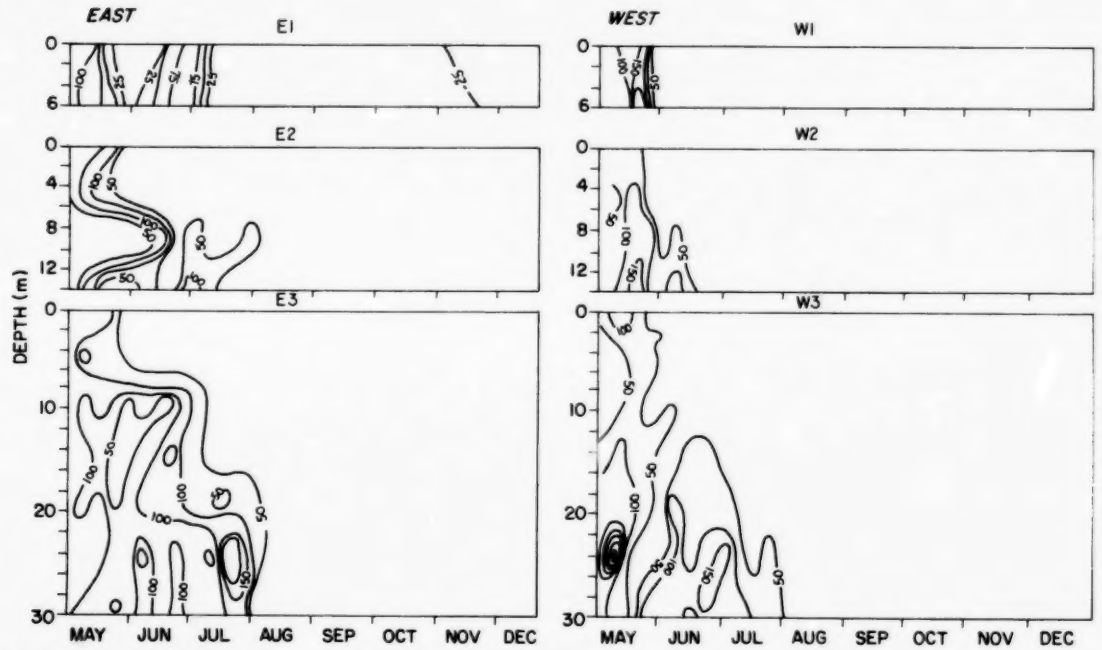

Fig. 4. Temporal and spatial distribution of *Melosira islandica* in the Toronto area of Lake Ontario, 1979. Note the sedimentation of the population in early June (cells.ml).

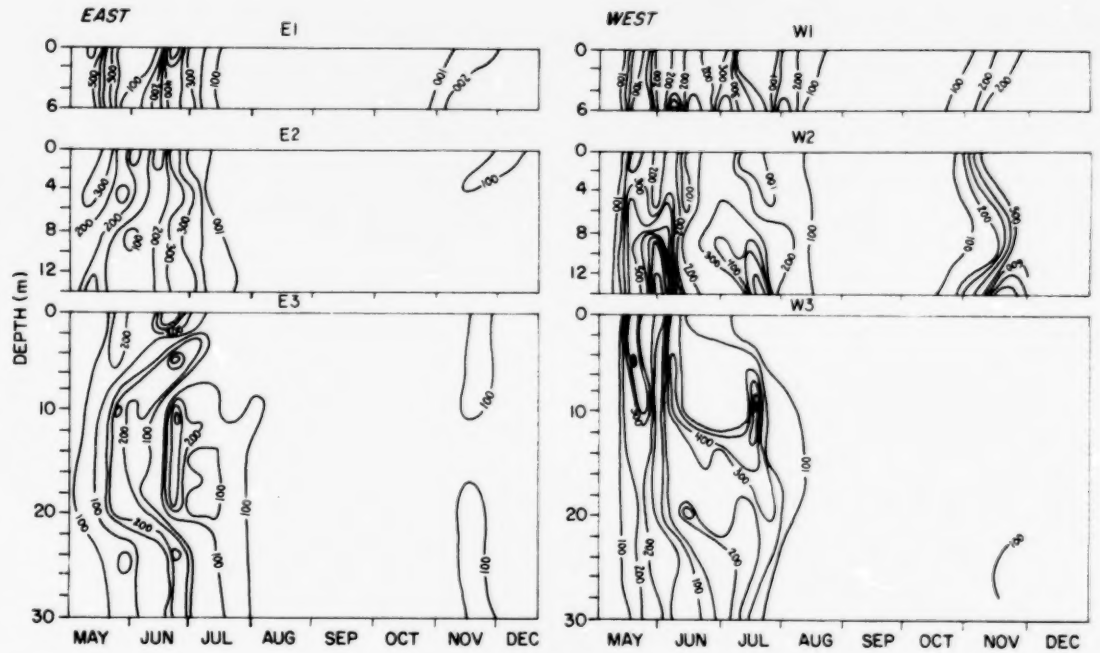

Fig. 5. Temporal and spatial distribution of *Asterionella formosa* in the Toronto area of Lake Ontario, 1979. Note the evidence of sedimentation of the population in early July (cells.ml).

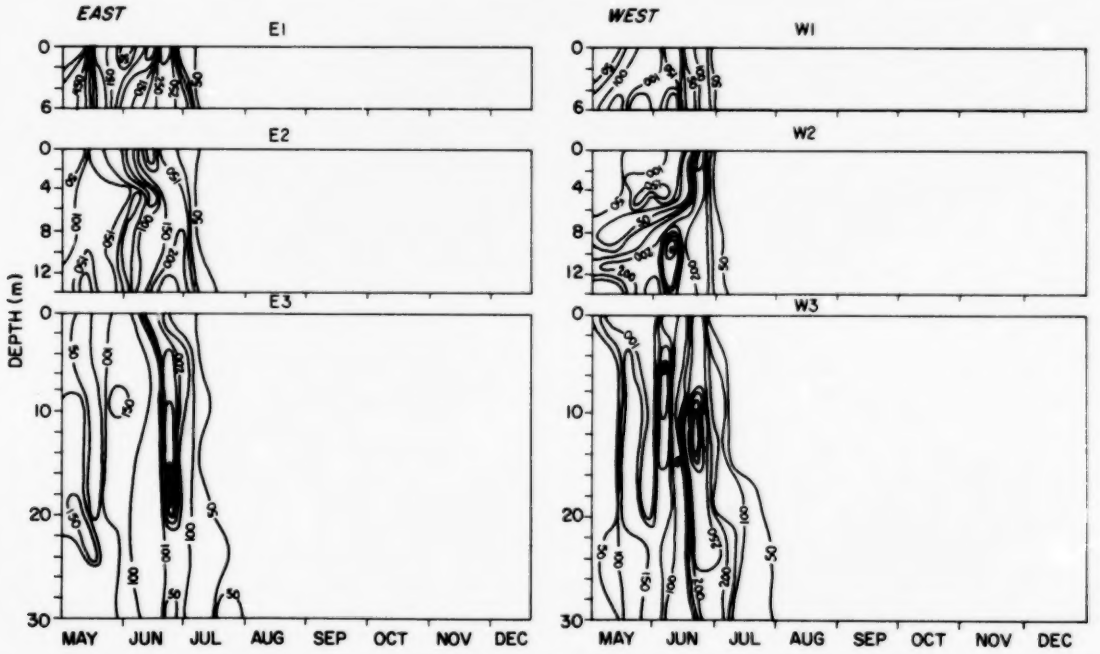

Fig. 6. Temporal and spatial distribution of *Synedra acus* in the Toronto area of Lake Ontario, 1979 (cells.ml).

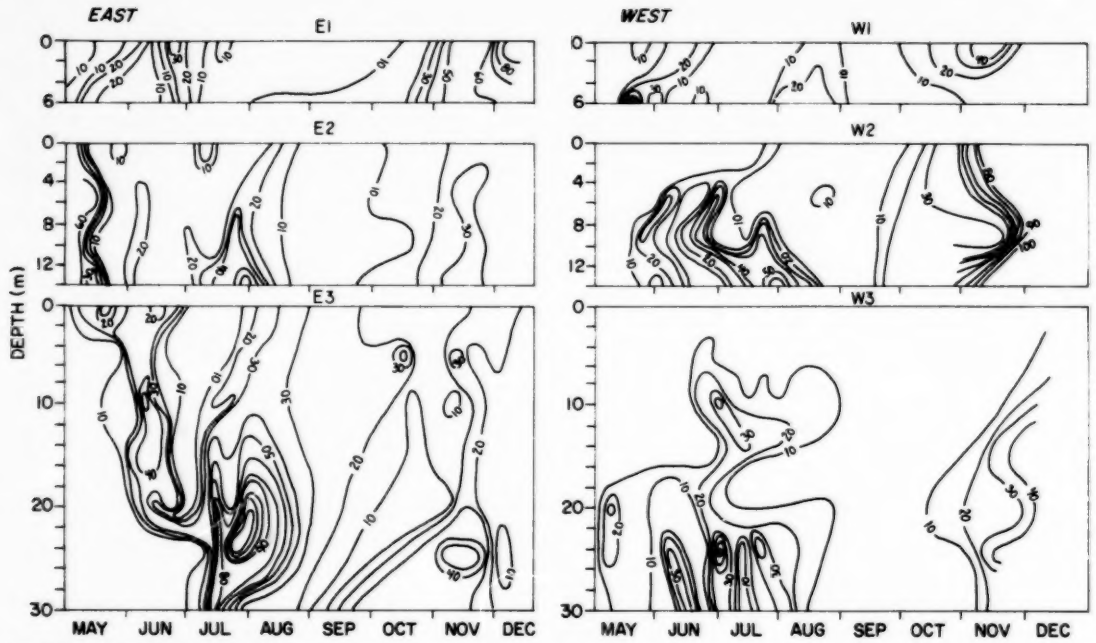

Fig. 7. Temporal and spatial distribution of *Tabellaria* in the Toronto area of Lake Ontario, 1979. Note how populations sediment out of the water column at the offshore stations.

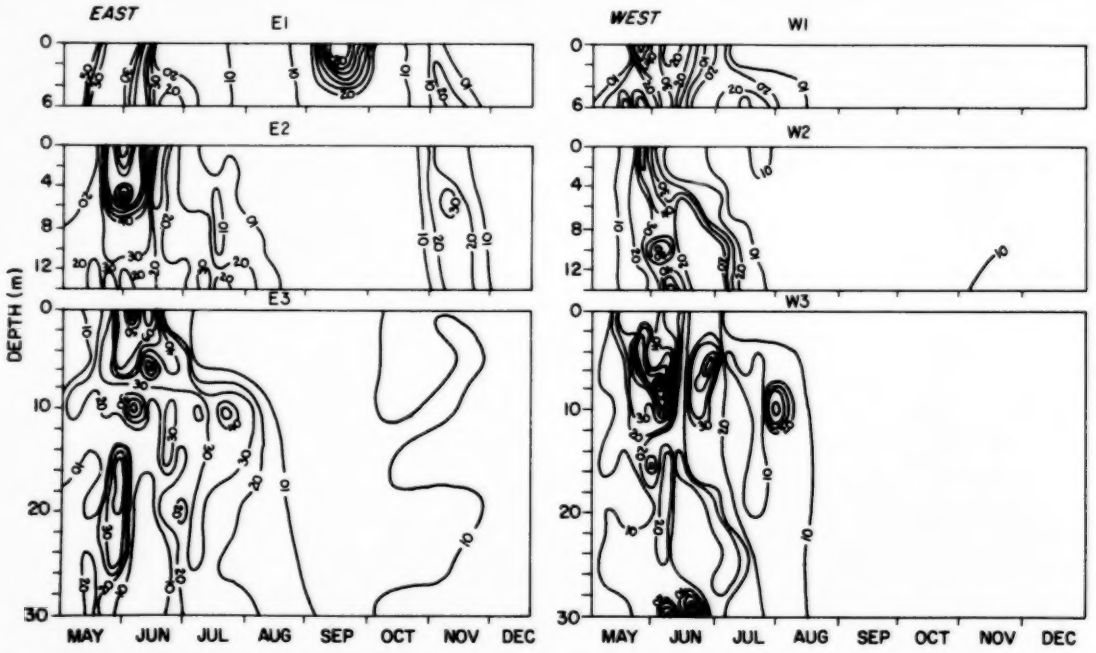

Fig. 8. Temporal and spatial distribution of *Gymnodinium* spp. in the Toronto area of Lake Ontario, 1979. This species tended to avoid the top few metres of the water column, perhaps selecting for a particular light intensity (cells.ml).

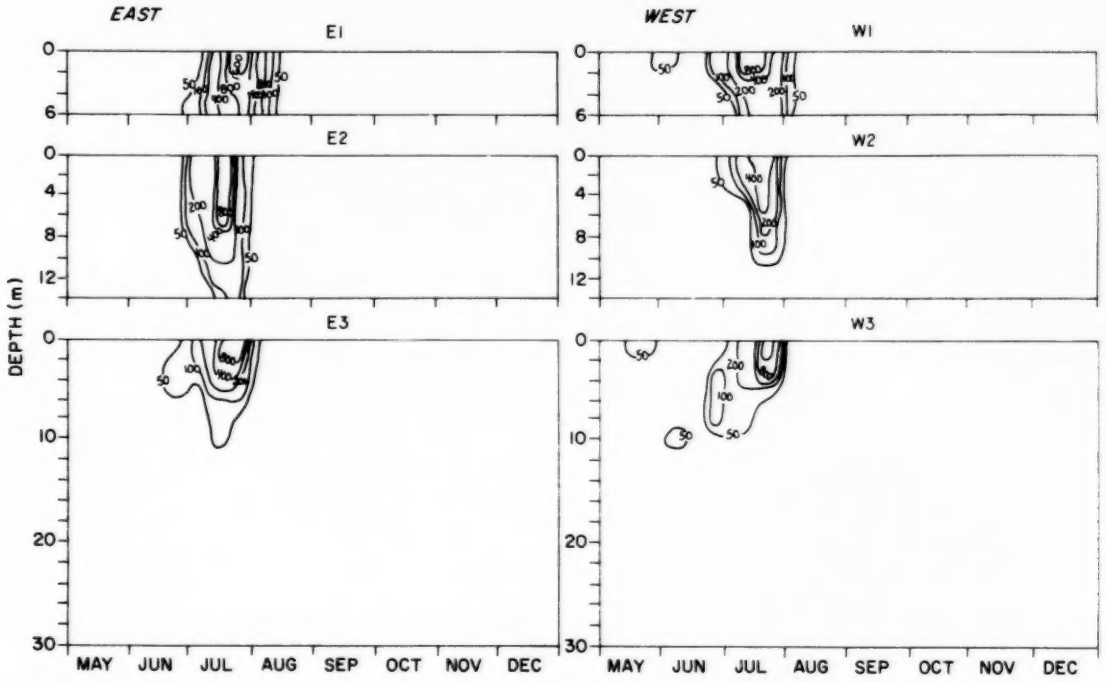

Fig. 9. Temporal and spatial distribution of *Dinobryon divergens* in the Toronto area of Lake Ontario, 1979. Summer populations tended to be confined to the euphotic zone (cells.ml).

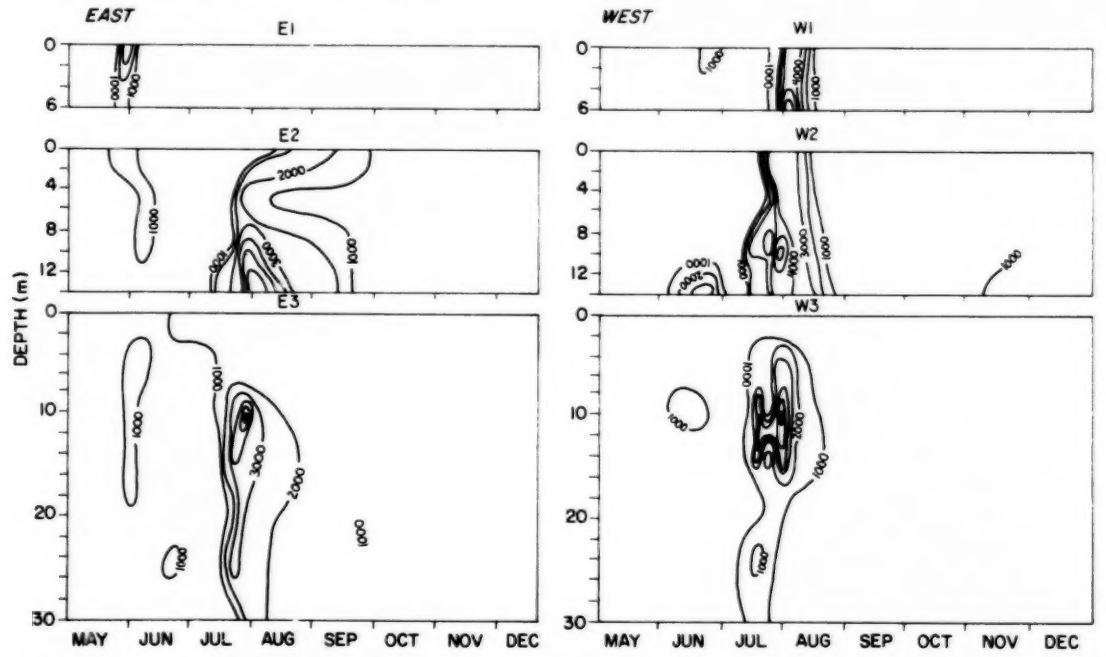

Fig. 10. Temporal and spatial distribution of *Oscillatoria* in the Toronto area of Lake Ontario, 1979. The figure illustrates discrete depth selection despite very low abundance (cells.ml).

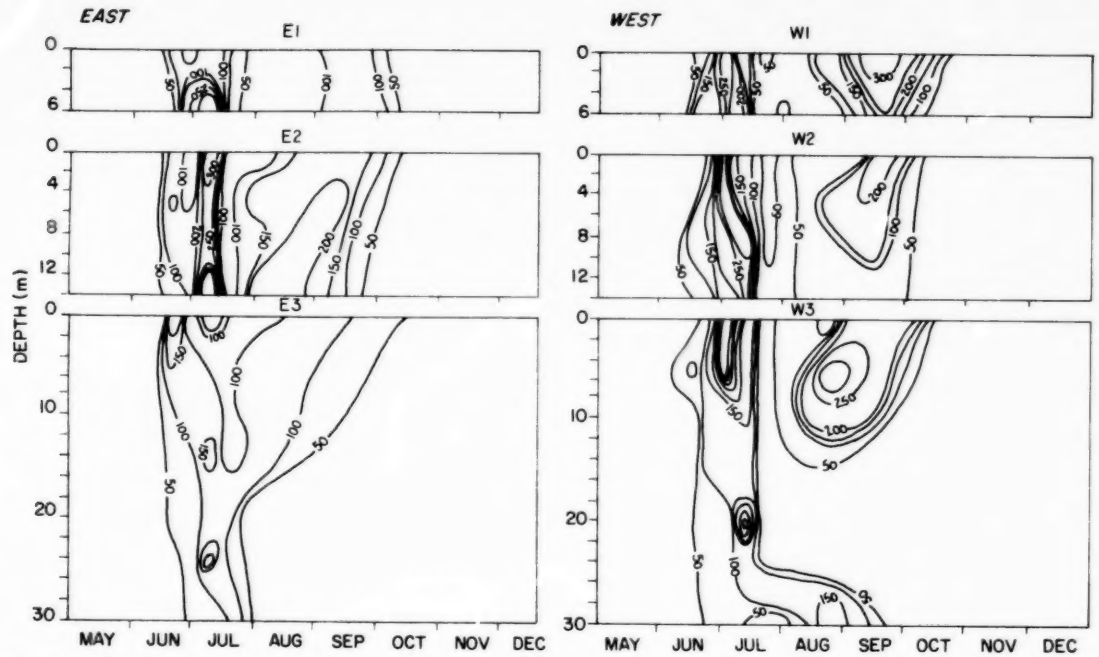

Fig. 11. Temporal and spatial distribution of *Cryptomonas ovata* in the Toronto area of Lake Ontario, 1979. Note the heterogeneous distribution with depth (cells.ml).

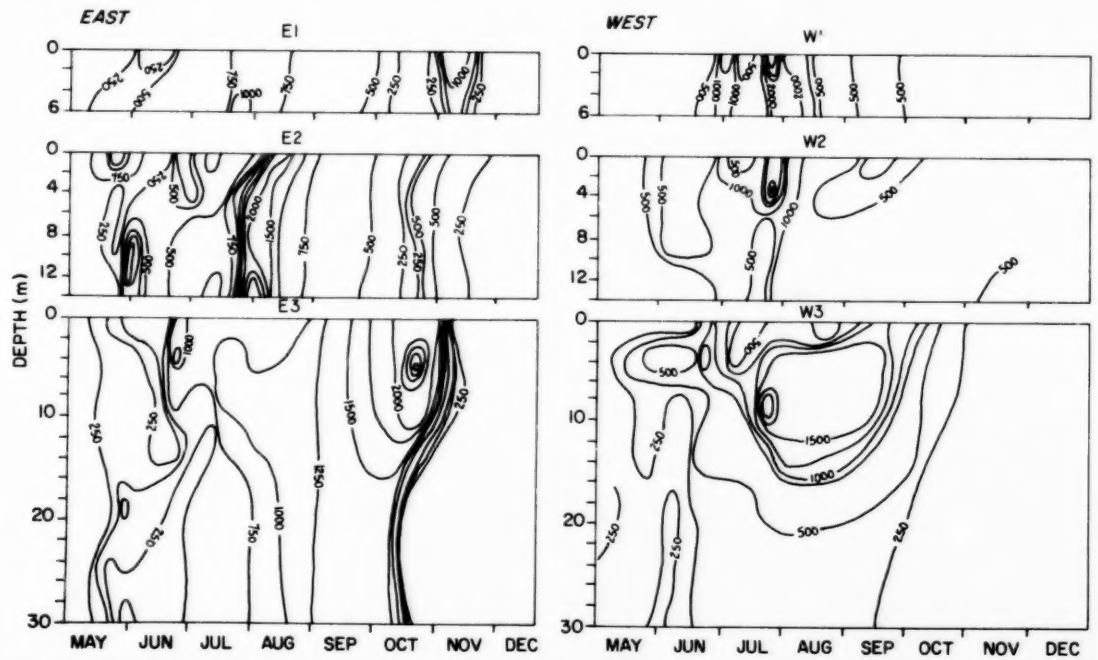

Fig. 12. Temporal and spatial distribution of *Rhodomonas minuta* in the Toronto area of Lake Ontario, 1979. Note the similar vertical distribution of *C. Ovata* (cells.ml).

WH) was composed of a diverse community of green algal species. At no time did a single species dominate the assemblage. Generally, the phytoplankton community was dominated by diatoms such as *Asterionella formosa* Hass., *Syndera acus* Kutz. and *Melosira islandica* Mull., and by cryptophytes such as *Cryptomonas ovata* Ehr, *Cryptomonas erosa* Ehr and *Rhodomonas minuta* Skuja. Other taxa that were less abundant were *Gymnodinium* during the spring and *Dinobryon divergens* Imhoff during the summer. Figure 3 shows that total algal volume illustrated little depth structure. Even during late July when the strongest thermal gradient was observed, there was no reflection of this in the vertical structure of the algal community.

Figures 4, 5 and 6 illustrate the seasonal distribution and abundance of *Melosira islandica, Asterionella formosa* and *Synedra acus*. The diatom populations were already declining when the study was initiated, and sedimentation resulting from warming of the water column and possible silica limitation became evident (see Titman & Kilham, 1976). Cells that were sedimenting out, however, were healthy and there was not an accumulation of dead cells that would be indicative of severe nutrient depletion (Hughes & Lund, 1962). The large diatom, *Melosira islandica*, sedimented out in mid-June and reappeared in late October with many dead cells, suggesting the fall inoculum was apparently dependent on resuspension from the sediments. *Asterionella formosa* sedimented out in early July followed by the smaller *Synedra acus*. As noted in Fig. 7, *Tabellaria fenestrata* (Lyngb) Kutz was maintained in the water column throughout the summer although there was evidence that a large proportion of the population had settled out by the middle of July 1979.

During the late spring, *Gymnodinium* was common in the upper few metres of the water column (Fig. 8) and was replaced by surface populations of *Dinobryon divergens* during the summer (Fig. 9). The collapse of the *Dinobryon* populations was not associated with any measured environmental parameter.

Oscillatoria (possibly *Oscillatoria limnetica* Lemmerman) also was found at discrete depths despite the weak thermal gradients. Populations were, however, very small and existed only for a short duration (Fig. 10). Figures 11 and 12 illustrate the seasonal abundance and distribution of *Crymptomonas ovata* and *Rhodomonas minuta*. These species, along with *Cryptomonas rostratiformis* Ehr. and *Cryptomonas curvata* Ehr. persisted throughout the year with some evidence of their accumulating in the euphotic zone. Their success in dominating the phytoplankton component over the year is interesting in that despite their motility, a large proportion of the population was continually observed below the euphotic depth (10 m).

Discussion

The physical processes of the coastal zone of Lake Ontario are complex because of the large size of the lake and the strong influence of day-to-day meteorological events (Blanton, 1974; Boyce, 1974). Haffner *et al* (1980) illustrated that the vertical phytoplankton assemblage in nearby Hamilton Harbour was influenced by small thermal gradients of less than 1 °C per metre. There has also been a considerable number of observations of deep layer phytoplankton maxima in the Great Lakes that are dependent on thermal structures. Bowers (1980) noted that the spatial and temporal variability of a deep chlorophyll *a* layer in Lake Michigan was dependent on physical factors such as oscillations of the thermocline, but unfortunately the species occupying this layer were not identified. The importance of physical processes, however, has been overshadowed by considerations of nutrient limitation even though there is little evidence of actual *in situ* phytoplankton growth in the Great Lakes being nutrient limited. Most evidence for the potential of nutrient limitation in the Great Lakes has come from 'bottle' or laboratory tests (Kilham *et al*, 1977; Schelske *et al*, 1978), and there is a need to be able to translate these results to the observed algal communities of the lakes (see Schelske, 1979).

The difficulty in translating these results is determining situation when steady state nutrient kinetics apply to the Great Lakes. Physical processes such as coastal jets (Csanady, 1972), upwellings (Lee, 1972) and thermal bar formations (Rodgers, 1965) make the coastal zone of Lake Ontario a very dynamic system. Blanton 1974 determined that the lake could respond within 6 hours to a meteorological change, and as such the coastal zone is not a steady state environment. Phytoplankton species must respond to these high frequency perturbutions

in the nearshore habitat, and it could be expected that the community would be composed of 'opportunistic' species.

Haffner *et al* (1980) argued that for algal species to adapt to environmental conditions there was a requirement for a critical period of temporal and spatial stability (see May, 1973). In Lake Ontario, Gachter *et al* (1974) concluded that physical processes such as upwellings were of such short duration that they were often associated with decreases in primary productivity (see also Haffner *et al* 1983). This concept of stability is also supported by Bowers (1980) who stressed the importance of unpredictable wind structure controlling biological events in Lake Michigan. Bowers (1980) noted the importance of euphotic depth/mixing depth ratio in the development of the deep chlorophyll *a* layer of Lake Michigan. Deeper and less distinct thermoclines destroyed the low turbulence upon which the algae of the deep layer maxima were dependent. Low turbulence would imply greater environmental stability within the zone, and hence the development of a more productive algal community. Within this type of community, interspecific competition could regulate the composition and abundance of phytoplankton species.

To understand the phytoplankton composition and abundance of the nearshore zone of the Great Lakes, there is a need to differentiate between the strategies which are related to changes in periods of environmental stability (seasonal) from those which are related to frequency of changes in environmental stability (meteorologically induced). For example, during the spring diatom growth, homogeneous mixing occurs for several weeks and diatom communities have sufficient time to become acclimated to deep mixing with low I_k values and low specific respiration coefficients (Harris & Lott, 1973). The long period of homogeneous mixing in the spring results in the development of large standing crops and strong interspecific competition for environmental resources such as silica. As turbulence becomes suppressed with the warming of the water, specific sinking rates also become important in determining species abundance and composition (Burns & Rosa, 1980; Smayda, 1971), thus the community is potentially regulated by both physical and chemical parameters. With respect to the present study it is probable the long duration of the period of homogeneous mixing (possibly 2.5 months) and the relatively low silica levels, that chemical regulation might be favoured.

Paradoxically, the development of thermal stability in the Great Lakes nearshore zone also represents the development of conditions resulting in the lowest ecological stability (i.e. frequency of environmental changes). Seiche effects, internal wave motions and upwelling/downwelling events cause high frequency changes in the vertical habitat of the phytoplankton. The vertical distribution of species found in Lake Ontario during 1979 illustrates that the populations can somewhat overcome these stresses, and are found in specific layers of the water column despite weak thermal gradients. The species richness of the nearshore zone and the lack of a defined community composition noted by Michalski (1969) can possibly be attributed to this lack of environmental stability and partitioning of the vertical habitat by different species.

Even though turbulence decreases during the summer period in the nearshore zone of Lake Ontario, it is apparently sufficient to maintain some diatom genera such as *Tabellaria*. *Tabellaria* possibly has a lower sinking rate than the other diatoms found during the 1979 study. As compared with *Melosia islandica*, *Tabellaria* had a longer chain structure and was possibly less heavily silicified. Its presence, however, stresses that turbulence is still a major factor in the nearshore zone during summer periods, and the discrete vertical structure of phytoplankton species observed during the same time period is possibly the result of some process of depth 'selection' by the various species involved. This selection could either be a result of motility, buoyancy control or the capability of rapid growth – a common attribute of opportunistic species.

As blue green algae require very stable water columns (Reynolds, 1972), the lack of representative blue-green algae in the nearshore zones of the deep Great Lakes might be explained by the complex mixing patterns common to these areas (Blanton, 1974). Only in areas of the Great Lakes where vertically stable water columns persist would these organisms be able to maintain themselves in the euphotic zone, and accumulate in layers during prolonged periods of stratification.

The cryptomonads on the other hand are a ubiquitous group, and are very common throughout the Great Lakes. Despite their motility, particularly as compared with species such as *Oscillatoria* and *Di-*

Table 3. Correlation matrix of 12 common species of phytoplankton in Lake Ontario northwest nearshore zone, 1979 (east transect). (All counts transformed $\log_{10}(x + 1)$.

'r' 1	2	3	4	5	6	7	8	9	10	11	12	
	.38	.53	-.15	-.14	.19	.28	.14	.06	.56	.14	-.02	1
		.28	.10	-.07	-.02	.05	.24	.22	.19	.45	.05	2
			-.02	-.15	-.07	.18	.30	.11	.35	.38	.04	3
				.28	.81	.08	.27	.38	-0.5	-0.2	.42	4
					.41	-.02	0.9	-.02	-.05	-.12	-.01	5
						-.09	.24	.41	-.15	.21	.46	6 'r'
							.07	.24	.33	.08	.12	7
								.42	.17	.48	.14	8
									.18	.42	.28	9
										.32	.22	10
											.19	11
												12

Species: 1 *Cryptomonas erosa*; 2 *Cryptomonas ovata*; 3 *Rhodomonas minuta*; 4 *Asterionella formosa*; 5 *Melosira islandica*; 6 *Synedra acus*; 7 *Tabellaria fenestrata*; 8 *Chlorella*; 9 *Scenedesmus bijuga*; 10 *Oscillatoria*; 11 *Raphidiopsis*; 12 *Gymnodinium* spp. (n = 201).

Table 4. Correlation matrix of 12 common species of phytoplankton in Lake Ontario northwest nearshore zone, 1979 (west transect). (All counts transformed $\log_{10}(x + 1)$.

'r' 1	2	3	4	5	6	7	8	9	10	11	12	
	.58	.07	-.22	-.30	-.25	-.14	.02	-.21	.17	-0.7	-.10	1
		.27	-.04	-.26	-.09	-.09	.23	.32	-.12	.11	.04	2
			-.06	-.22	-.19	-.07	.24	-.04	.30	.42	-.01	3
				.03	.42	.29	.04	.46	.23	.29	.05	4
					.32	.15	-.05	.19	-.17	-.25	.19	5
						.05	0.6	.42	-.16	.00	.34	6 'r'
							0.2	.26	.13	.00	-.06	7
								.27	.07	.70	.04	8
									.06	.16	.28	9
										.08	-.02	10
											-.01	11
												12

Species: 1 *Cryptomonas erosa*; 2 *Cryptomonas ovata*; 3 *Rhodomonas minuta*; 4 *Asterionella formosa*; 5 *Melosira islandica*; 6 *Synedra acus*; 7 *Tabellaria fenestrata*; 8 *Chlorella*; 9 *Scenedesmus bijuga*; 10 *Oscillatoria*; 11 *Raphidiopsis*; 12 *Gymnodinium* spp. (n = 181).

nobryon, it is surprising to find there is little depth selection within the euphotic zone. Haffner *et al* (1980) found that cryptomonads were not found in areas of anoxia in Hamilton Harbour, and because of low chlorophyll *a*:cell volume ratios, hypothesized that the population was capable of a heterotrophic existence. Again this explanation would be consistent with the observation of the vertical distributions of crypotomonads in the nearshore zone of Lake Ontario.

Tables 3 and 4 summarize correlation matrices of the 12 most common species of phytoplankton found in Lake Ontario in 1979 along the east and west transect respectively. There was considerable similarity between the species composition of the two transects. There are, however, some distinctive differences such as an association between *Asterionella* and *Synedra*. These genera are closely correlated on the east transect but are not correlated along the western transect. Generally, however, there are only a few ecologically significant ($r^2 > 0.5$) species associations within the phytoplankton communities of the east and west transects. In other words, evidence for interspecific

competition is not observed, as would be expected in an assemblage which is being determined by physical perturbations.

Species which are commonly associated with eutrophic conditions in the Great Lakes such as *Melosira granulata* (Ehr) Ralfs, *Stephanodiscus astraea* (Ehr) Grun, and *Fragilaria crotonensis* Kitton have been demonstrated to also be somewhat dependent on physical processes. Shear *et al* (1979) demonstrated the dependence of the growths of *Melosira* on light and temperature in Lake Ontario, and Chandler (1940) noted that *Stephanodiscus* was confined to areas of high turbidity. Recently Nicholls *et al* (1980) found diatom densities in western Lake Erie were negatively correlated with water depth such that a summer growth of *Fragilaria* might have been influenced by turbulence and resultant resuspension. In all these circumstances, as in this study, physical factors played a major role in determining the periodicity and in some cases the size of algal growths within the Great Lakes.

In the above paragraph selected references were used to emphasize the importance of physical factors, and that what is required are studies on the interaction of the physical and chemical factors that regulate phytoplankton communities. As argued by Parker (1975) one cannot assume plant growth depends solely (and proportionately) on nutrient availability because time delays can uncouple the regulating influence and result in potential instability (May, 1973). Not only are the physical and chemical factors interactive, they are also interdependent. Until such studies are done, knowledge gained from laboratory experimentation can only be tentatively applied to *in situ* observations. Schelske (1979) questioned whether there was a controversy of phosphorus being the limiting nutrient in the Great Lakes. In essence, however, the controversy is not whether phosphorus is limiting, but what is the ecological role of phosphorus – a question of availability and utilization.

With the exception of the cryptomonad population and the spring diatom pulse, phytoplankton production in the nearshore zone of Lake Ontario is basically dominated by non-steady state dynamics. It is possible the lack of species associations, and the lack of dominant species in the summer assemblage are a function of the physical variability of the area. Low, persistent algal volumes during 1979 suggest there are a few periods where populations can achieve their potential maximum crop indicative of the nutrient status of the nearshore zone. In other words, for an algal population to exploit resource levels requires a critical period of time, but during the summer the physics of the nearshore zone is such that this time requirement is not often met. The similarity of inshore and offshore productivity values within the literature would suggest factors other than simple nutrient concentration or light intensity values were also regulating the productivity of the nearshore zone. Until the production dynamics of non-steady state systems are understood, it is unlikely that the phytoplankton community can be directly related to the availability and utilization of the nearshore zone of the nutrient resource of the Great Lakes.

Conclusions

The phytoplankton community of the north west nearshore zone of Lake Ontario showed considerable vertical structure despite the absence of strong density layering in the water column. Information presented here suggests this vertical structure might be a common feature of nearshore algal populations of large lakes as it was observed along two separate transects.

Because physical processes influence community structure and phytoplankton diversity, it was difficult to observe species associations in such systems and it is possible there is little interspecific competition for nutrients except during periods of homogenous mixing. Analysis of the summer phytoplankton species assemblage and the lack of dominant species in the assemblage suggest that populations cannot respond to high frequency physical perturbations. For these reasons it is probable that phytoplankton composition and abundance of the Great Lakes are not simply related to nutrient loadings and resultant enrichment. Non steady state nutrient dynamics should be studied in preference to steady state kinetics in order to understand the production ecology of nearshore zones.

Acknowledgements

The authors wish to acknowledge the assistance of Ministry of the Environment field crews for the

collection of samples, and the efforts of I. Grey and M. Morris during the analysis of the samples. M. Morin and T. Verzosa typed the manuscript and the figures were prepared by Y. Gagne and M. Steeves. The authors (G.D.H. and P.D.N.H.) acknowledge financial assistance of respective grants from N.S.E.R.C.

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Received 20 May 1983; in revised form 6 October 1983; accepted 15 October 1983.